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13. ABSTRACT (Maximum 200 words)

We have constructed two Selected Energy Epitaxial Deposition (SEED) systems for the growth of wide bandgap semiconductors, specifically GaN and SiC. The first system is a seeded beam supersonic free-jet (SSJ) which will eventually be interfaced directly to our existing low-energy electron microscope (LEEM) to conduct *in situ* observations of the growth of epitaxial layers of GaN in real time. A beam intensity of 2×10^{19} atoms/srrad/sec is obtained with a 500 sccm flow in the SSJ. With the beam seeded with 10% NH_3 and a nozzle to substrate distance of 50 cm, this intensity corresponds to 1×10^{15} molecules/cm^2/sec. The second instrument is a dual Colutron deposition system to provide mass-separated monoenergetic ion beams in the 5-20 eV range for direct ion-beam deposition. This involves the modification of our two existing Colutron ion-beam systems originally designed for low-energy ion-scattering spectrometry. The completed Colutron deposition system has been tested to produce an Ar^+ ion beam at 20 eV with FWHM of 3 eV and an ion current density of $\sim 10^{12}$ cm^{-2} s^{-1}.

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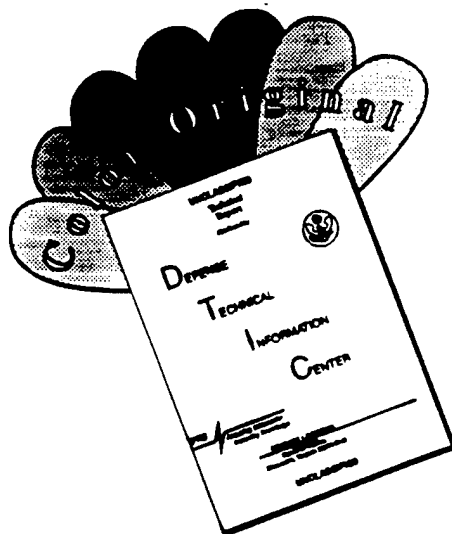
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1.   Seeded Beam Supersonic Free-Jet (SSJ) Source

The use of an SSJ source to enhance the surface decomposition of silane and methane has been demonstrated by Jones et al. [1] and Ceyer et al. [2] respectively. The success of the SSJ is attributed to its capability of tuning the kinetic energy of the molecular species such that bond deformation and cleavage occur upon contact with the substrate. If the available kinetic energy is higher than the barrier for chemisorption on the substrate surface, then some of the remaining energy can be used to enhance surface diffusion of the adsorbate to promote layer growth. In view of these desirable attributes, the SSJ constitutes a viable technique for the growth of single-crystalline films of GaN.

The design of the SSJ is shown in Fig. 1 and the completed SSJ source is shown in Fig. 2. The major constraint in the design is dictated by the need to interface the source to the low-energy electron microscope (LEEM). This places certain restrictions to the height and size of the SSJ source. Another consideration is that the source requires high stagnation pressures to obtain narrow energy distributions and high intensity. The LEEM, however, is an UHV microscope with a base pressure in the 10^{-11} torr range, although it will operate at a pressure of 10^{-7} torr with a backfilled gas. Thus in order to keep a pressure of no higher than 10^{-7} torr in the LEEM, the SSJ source is designed to have two differentially pumped compartments to decrease the gas load and to collimate the beam. These compartments are indicated by the internal partitions shown in Fig. 1(b).

The source subchamber (on the left of Fig. 1b) is pumped by a Varian VHS-10 diffusion pump backed by a combination of a Leybold WSU 501 Roots blower and a Leybold D65-BCS rotary vane pump. This gives a maximum throughput of 7.7 torr l/s and a pressure of 0.5 - 1.0 mtorr. The first differentially pumped compartment (lower right of Fig. 1b) is evacuated by a Varian VHS-4 diffusion pump with a Varian 362-4 cryotrap, giving a pressure of 5×10^{-6} - 1×10^{-5} torr. The second differentially pumped compartment (upper right of Fig. 1b) is evacuated by a Leybold TMP 340M magnetically suspended turbomolecular pump, giving a pressure of 5×10^{-8} - 1×10^{-7} torr for this part of the SSJ source.

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Alignment of the beam and the skimmer to optimize beam intensity and energy distribution is carried out by an x-y-z manipulator mounted vertically on top of the source chamber to move the beam nozzle. Apertures of various sizes can be fitted to nozzle to accommodate different operating pressures in the source.

The supersonic molecular beam from the SSJ source was analyzed by a time-of-flight (TOF) spectrometer. Fig. 3 shows the energy spectra at room temperature (300K) and a value of P_0D (nozzle pressure-diameter product) of 63 torr-cm for pure He and a 10% NH_3/He mixture. The very narrow energy distribution, 0.002 eV, of the pure He beam was broadened to 0.022 eV when seeded with the heavier NH_3, as expected. The NH_3 energy distribution has two peaks. The peak at higher energy is due to monomers and the lower energy peak is due to multimers in the seeded beam.

2. Dual Colutron Ion-Beam Deposition System

The deposition system consists of two Colutron ion beam units, each of them equipped with a Wien Filter to select the mass of the desired ion and an electrostatic deceleration lens to produce low-energy ions in the ~10 eV range. The system is further equipped with a RHEED unit for *in situ* monitoring of film growth, a 4-grid retarding field analyzer to conduct LEED and AES studies for structural and compositional determination of the film surface, and an electrostatic energy analyzer to measure the energy distribution of the ion flux. The complete deposition system is shown in Fig. 4. The sample chamber is entirely UHV compatible, with a base pressure of 1 x 10^{-10} torr.

We have succeeded in obtaining Ar^+, N_2^+, N^+, and C^+, ion beams at energies 10-20 eV with current densities ~200 nA cm^{-2}, corresponding to a deposition rate of ~10^{-3} MLs^{-1}. The energy distribution of the Ar^+ ions at 20 eV measured by the electrostatic energy analyzer (ESA) is shown in Fig. 5. The FWHM is ~ 3 eV. Most of the broadening is due to multiple scattering of the ions from surfaces before entering the ESA. With suitable alignment of the ion beam, we expect to achieve a FWHM of < 1 eV in the energy distribution.

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3.   Arc-Heated Nitrogen Atom Source

We have acquired the parts and blueprints arc-heated supersonic free-jet source developed for molecular beam scattering experiments from the Max-Planck-Institut für Strömungsforschung in Göttingen, Germany. The fabrication of such a source with minor modifications is under way. We anticipate to produce a nitrogen atom beam with adequate flux with this source for the growth of GaN thin films. Energy analysis of the N atom beam will be carried out in our TOF spectrometer.

References

1.   M.E. Jones, L.Q. Xia, N. Maity and J.R. Engstrom, Chem. Phys. Lett. **229**, 401 (1994)

2.   S.T. Ceyer, J.D. Beckerle, M.B. Lee, S.L. Tang, Q.Y. Yang and M.A. Hines, J. Vac. Sci. Technol. **A5**, 501 (1987)
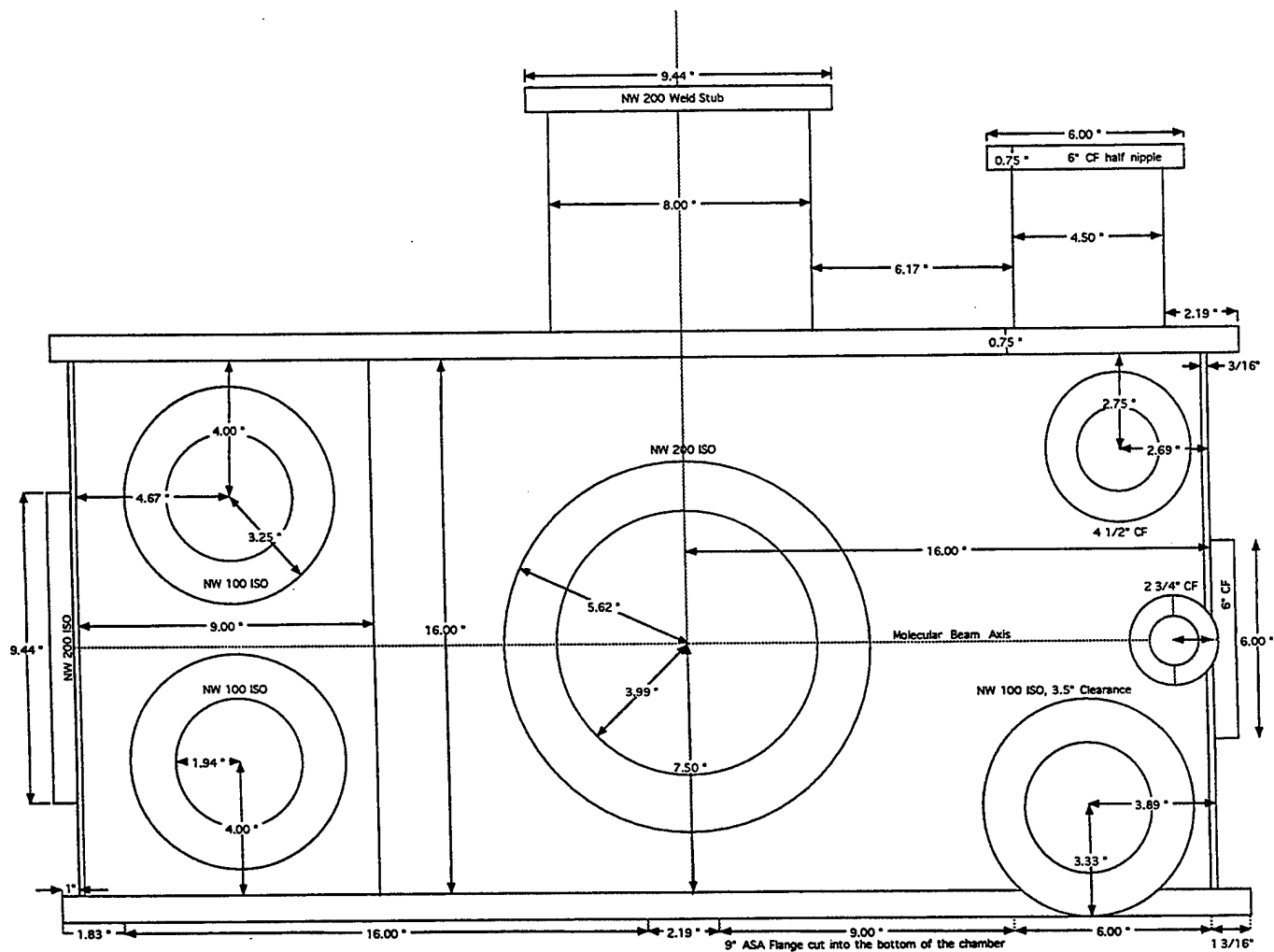
Fig. 1a. Right side view of the seeded beam SSJ source at ASU

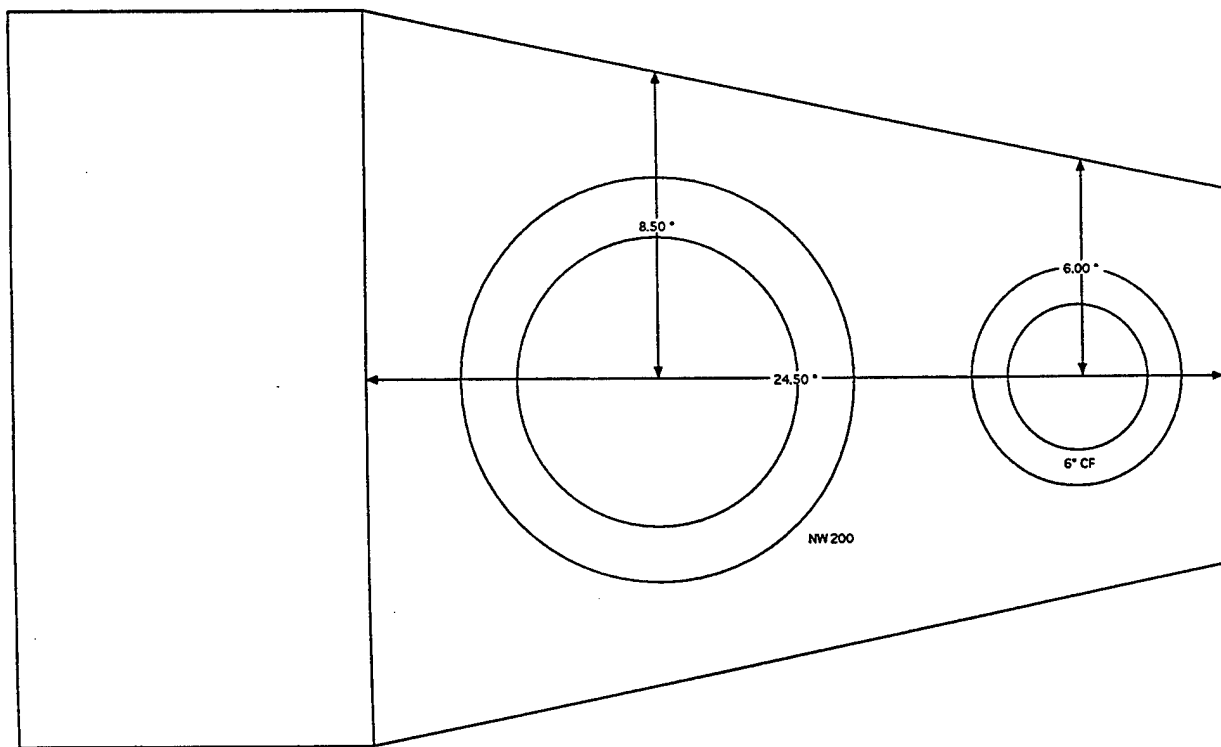Fig. 1b. Cross sectional view of the seeded beam SSJ source at ASU

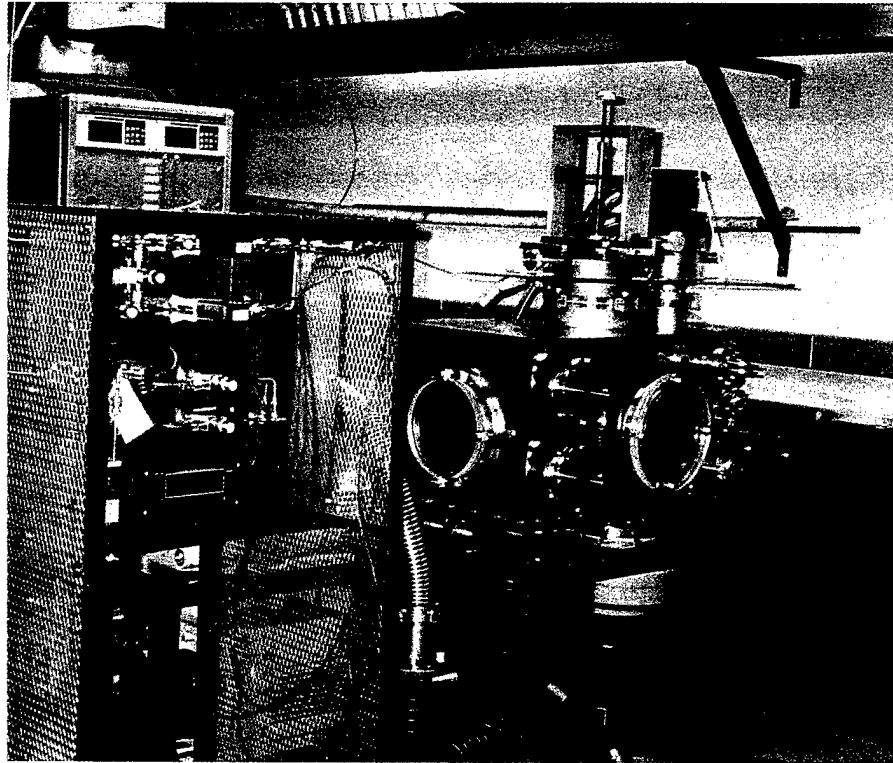Fig. 1c. Top view of the seeded beam SSJ source at ASU
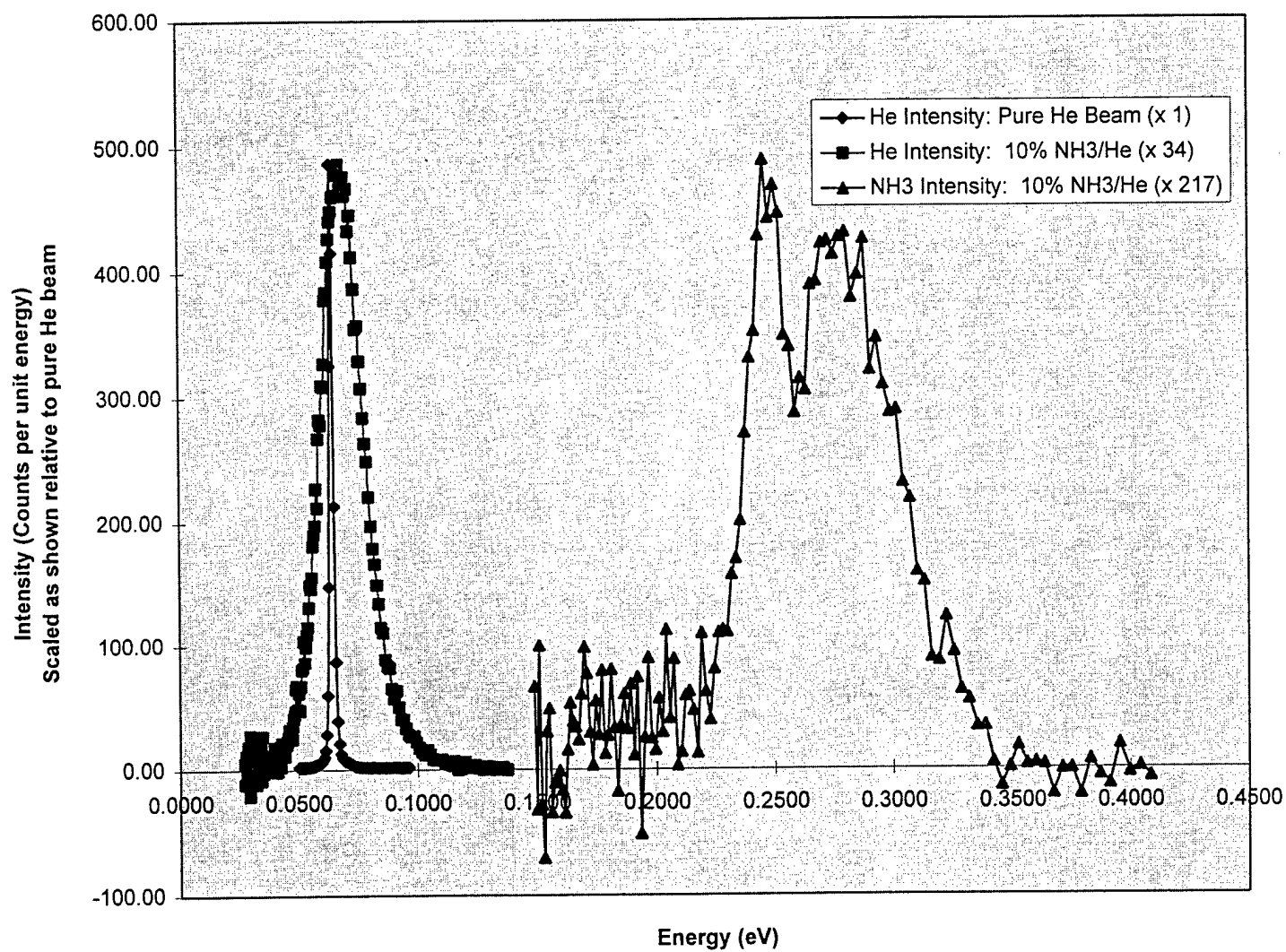
Fig. 2. Seeded beam SSJ source at ASU

Figure 3. Seeded Beam Energy Distributions.
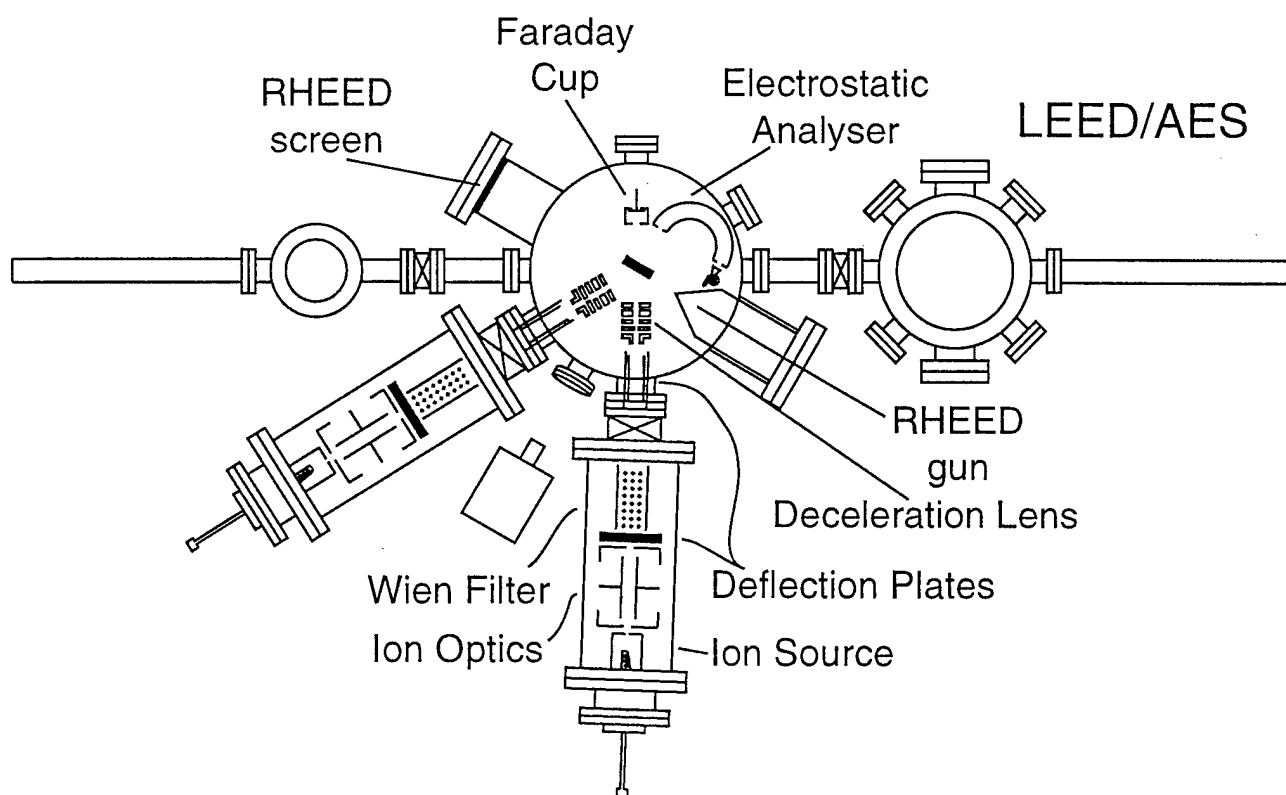10% Ammonia Seeded into Helium.
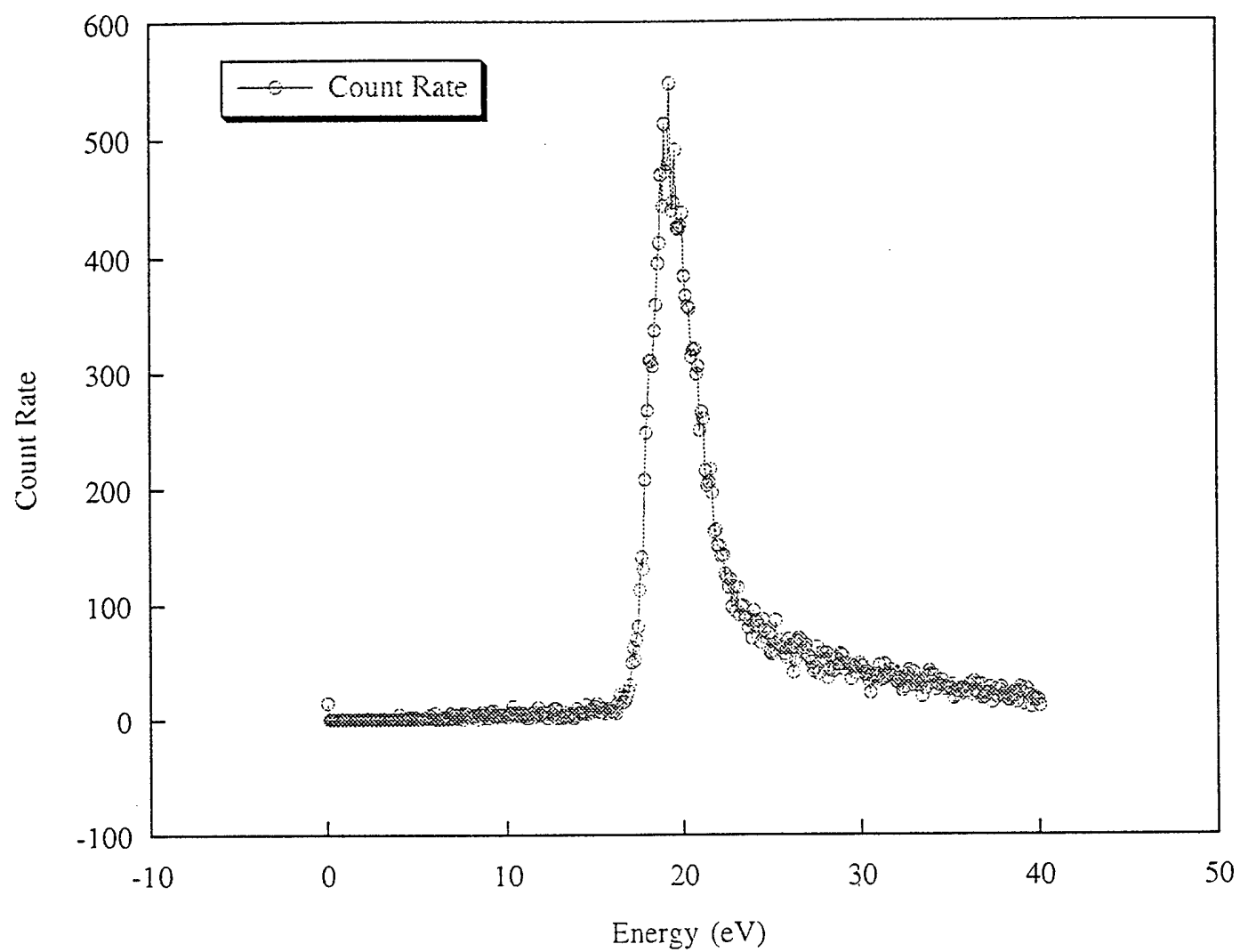
Fig. 4 Dual Colutron ion-beam deposition system

Fig. 5 Energy distribution of an Ar$^+$ ion beam at 20 eV.